Measurement of the Sea Spray Droplet Size Distributions at High Winds

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LONG-TERM GOALS

Improved understanding of fundamental processes of turbulence and sea-spray interactions under very strong wind conditions.

OBJECTIVES

This project will develop cloud droplet probes and phase-Doppler anemometry for measuring size-segregated droplet concentrations at high wind speeds in the ABL. The data will be used for investigating droplet dynamics in the marine atmospheric boundary layer, characterizing the droplet surface flux source function, and determining the effect spray drops have on air-water surface exchange processes. A physically based parameterization of droplet production in terms of wind/wave variables will be developed.

APPROACH

The fundamental parameter required for representing the effect of sea spray on air-sea exchange processes is the size dependent *source function* for droplets, or number of droplets of a given size produced at the sea surface per unit surface area per unit time as a function of wind speed. Because the source function cannot be measured directly at present, it must be estimated from the height-dependent number-size distribution of droplets, $n(r, z)$ (i.e., the number of droplets of given radius, r, per unit volume of air per increment of radius at height z) and a model for the atmospheric boundary layer that incorporates droplet dynamics. However, progress in determining the source function has been frustrated due to the difficulty of measuring $n(r, z)$. The present droplet source function parameterizations are based on droplet concentrations determined on a beach [*Smith et al.*, 1993], 10 hours of data at a wind speed of 21 m/s from the HEXOS program [*de Leeuw*, 1990], and inferences from various laboratory studies. The data from *Smith et al*. [1993] were recorded for U up to 30 m/s

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but, besides not being representative of the open ocean, contain no measurements of the larger size (r>20 :m) droplets believed to be important in air-sea exchange processes. In this project two different aircraft-mounted particle-sizing instruments will be used to measure droplet concentrations at high wind speeds (including hurricanes), and this data will be used in droplet dynamics models (Kepert et al., 1999] to estimate droplet source functions at very high wind speeds.

Because droplet measuring instruments often yield conflicting results, we plan to pursue at least two measurement technologies with an emphasis on understanding the measurements and reconciling their disagreements. The first technique is a cloud/precipitation droplet probe (CPDP) based on optical droplet imaging methods. The second droplet measurement method will be based on a phase-Doppler anemometer (PDA). Both cloud droplet probes and PDA's are commercially available and can be deployed from an airplane to measure droplet concentrations. We will conduct these aircraft measurements as part of the intensive field experiments associated with the hurricane science team of the ONR Coupled Boundary Layer/Air-Sea Transfer (CBLAST) DRI. In addition to the aircraft measurements, we will also conduct additional field experiments in the surf zone and laboratory measurements in wind-wave tunnels.

Dr. Chris W. Fairall from NOAA Environmental Technology Laboratory and Dr. William E. Asher from the University of Washington Applied Physics Laboratory will collaborate on this joint proposal to evaluate both instruments. Dr. Fairall will be direct the measurements made with the CPDP and Dr. Asher will direct the research conducted with the PDA. Drs. Fairall and Asher will collaborate with Dr. Mike Banner (UNSW - University of New South Wales, Australia) on developing a parameterization of droplet production in terms of breaking-wave properties as diagnosed in numerical wave models. The aircraft work will be done in collaboration with Drs. Pete and Robert A. Black, NOAA AOML.

WORK COMPLETED

Funding for this project was received near the end of FY01. In the first year the a commercially available droplet probe [Model CIP airborne cloud imaging probe from Droplet Measurement Technologies (DMT)] was ordered and C. Fairall visited UNSW to meet with Mike Banner and initiate collaboration on linking sea spray production and numerical modeling of oceanic surface wave growth and breaking. In February 2002, C. Fairall met Mike Banner, Simon Change, and Peter Black at the AMS annual meeting in Orlando to discuss plans for the upcoming hurricane season flights on the NOAA aircraft and future wind tunnel work at UNSW. In May 2002 the CIP was shipped to McDill AFB in Tampa for integration in the NOAA WP-3D. However, no flights were made because the wing pod failed its stress test so the probe had to be removed, the pod removed, and OMAO commenced construction of a new wing pod.

In January and February of 2003, Drs. Fairall and Asher participated in a wind-wave tunnel for the Spray Production and Dynamics Experiment (SPANDEX). A total of 49 spray droplet concentrations were measured under different experimental conditions. Processed data are available on the ETL ftp site (ftp://ftp.etl.noaa.gov/et7/users/cfairall/onr_droplet). Droplet profiles were made at three different forcing (wind stress) and three water salinities. These data verified the basic profile scaling laws used for the ETL sea spray parameterization. In August 2003, C. Fairall visiting Penn State University and met with CBLAST investigators working on the LES modeling of the sea spray boundary layer to aid implementation of the ETL spray parameterization in their work. In late August 2003 the ETL CIP was installed on the NOAA P-3. A total of 6 flights were made (in hurricanes Fabian and Isabel) with a series of stepped profiles in the lower boundary layer. The CIP obtained usable data in the first 5 flights.

RESULTS

Discussions with Mike Banner and associates in 2001 led to the first steps in the development of a new parameterization of sea spray production. A writeup on the model physics was circulated to a list of interested CBLAST investigators. In 2003 a much simplified, parameterized version of the physical model was produced that is more practical for use in mesoscale models (see the ETL ftp site).

We are now working with Mike Banner and Bill Asher to complete analysis of the SPANDEX data. Figure 1 shows a summary of droplet measurements at three wind forcings (friction velocity values of 1.2, 1.6, and 1.8 m/s (equivalent to a 10-m wind speed over the ocean of 24, 29, and 33 m/s); results for measurements at 12.5 and 15 cm above the mean water surface are shown for each forcing. The droplet spectra are presented as the volume of water for each droplet radius. The total mass of suspended droplet water is the integral of this spectrum over all radii (multiplied by the density of water). The actual concentrations have been corrected to the effective source height (about wave crest height of 10 cm). The graph illustrates the rapid increase in spray concentrations (i.e., droplet production) with forcing. We plan to use the complete data from SPANEX to evaluate the scaling assumptions of the physical model of droplet production.

The CIP data from the hurricane flights have not been analyzed in detail. The data from the first two step profiles (Sept. 2 and 3, 2003) from hurricane Fabian have been examined briefly. On Sept. 2 the profile was made in an area with a 10-m wind speed of about 25 m/s and no droplets were observed even at the lowest altitude (83 m). On Sept. 3 profiles were made in a region with a 10-m wind speed of about 28 m/s and droplets were observed in concentrations roughly consistent with ship-based measurements at 22 m/s. The next year will be primarily devoted to analyzing the hurricane data.

IMPACT/APPLICATIONS

This work will lead to improved treatment of air-sea fluxes for wind speeds exceeding 20 m/s. Primary application will be in numerical forecasting models in conditions with mid-latitude and tropical cyclones.

TRANSITIONS

Droplet parameterization now implemented in ETL version of the WRF mesoscale model.

RELATED PROJECTS

"Mid-Oceanic Wintertime Surface Fluxes and Atmospheric Boundary Layer Structure: Relationship to Cyclone Development and Evolution", NSF. O. Persson, P.I.

SUMMARY

We have taken preliminary steps in formulating a new physical model of sea spray droplet formation and initiated contact with UNSW for laboratory simulations of the processes. A preliminary version of the model has been given to CBLAST numerical model groups; a simplified, parameterized version has also been distributed. In the fall of 2003 we anticipate acquiring long-needed measurements of sea spray concentrations over the oceans in near hurricane force winds (30-35 m/s). A wind tunnel study was conducted in the winter of 2003. If successful, we can make progress on a parameterization of spray production and an evaluation of spray thermodynamic effects on hurricanes.

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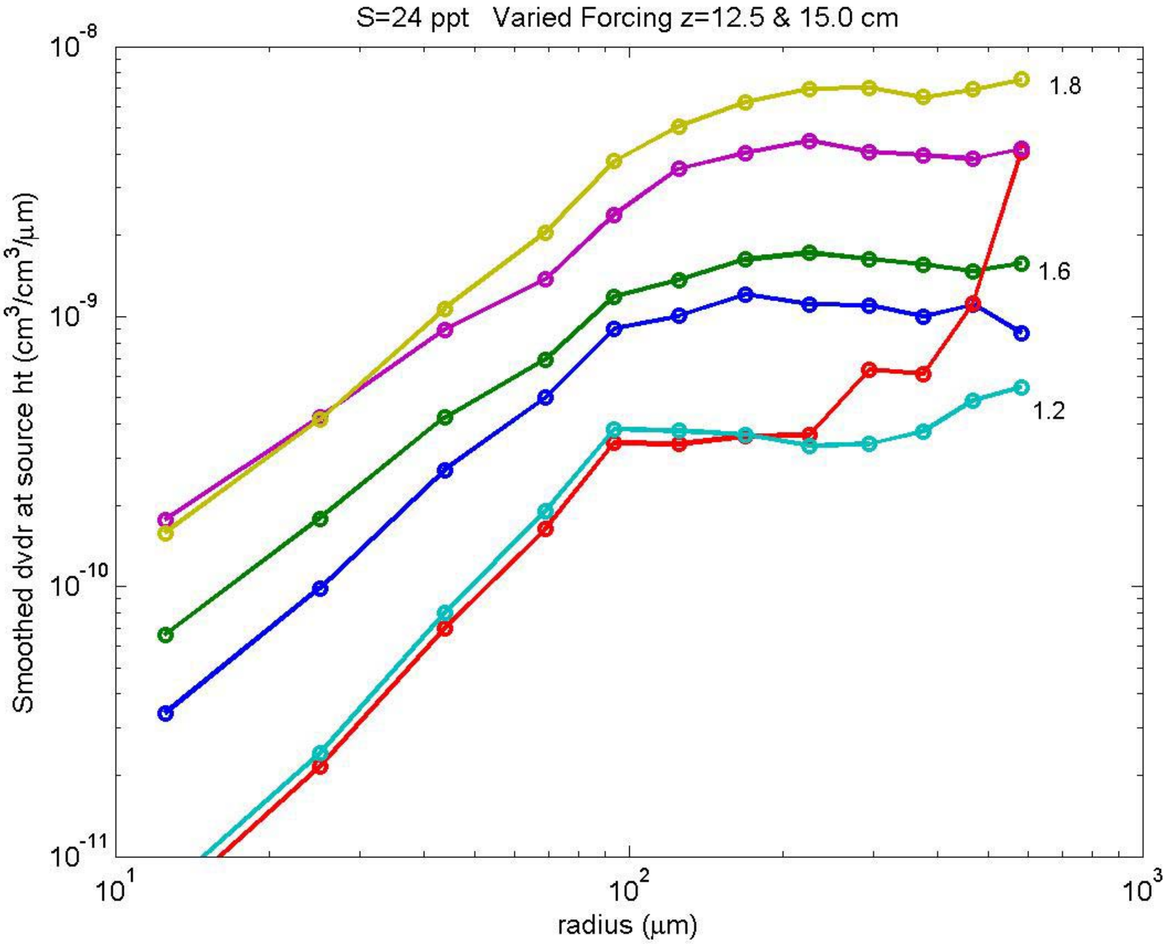

Figure 1. Sea spray droplet volume size spectra as a function of droplet radius for 3 different values of friction velocity, u_* (data from the SPANDEX wind-wave tunnel study performed at the Manly, Australia, wind-wave tunnel in 2003). Two spectra are given for each forcing - 12.5 and 15 cm above mean water. In terms of droplet volume (i.e., $4/3Br^3$ times the droplet number concentration), a broad peak occurs for droplets of about 200 micron (0.2 mm) radius. The limiting factor for small droplets is the availability of TKE to form droplets; for large droplets it is the availability of suitable wind gusts to eject the droplets away from the sloping wave surface.

[The droplet volume spectrum is the effective water volume assuming the droplets are spheres; multiplied by the density of liquid water, at a given height it gives the mass of water in the form of sea spray ejected from the surface.]